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SOIL PHYSICS

Modelling Thermal Diffusivity of Differently Textured Soils

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Abstract—A series of models has been proposed for estimating thermal diffusivity of soils at different water contents. Models have been trained on 49 soil samples with the texture range from sands to silty clays. The bulk density of the studied soils varied from 0.86 to 1.82 g/cm^3; the organic carbon was between 0.05 and 6.49%; the physical clay ranged from 1 to 76%. The thermal diffusivity of undisturbed soil cores measured by the unsteady-state method varied from 0.78×10^{-7} m^2/s for silty clay at the water content of 0.142 cm^3/cm^3 to 10.09×10^{-7} m^2/s for sand at the water content of 0.138 cm^3/cm^3. Each experimental curve was described by the four-parameter function proposed earlier. Pedotransfer functions were then developed to estimate the parameters of the thermal diffusivity vs. water content function from data on soil texture, bulk density, and organic carbon. Models were tested on 32 samples not included in the training set. The root mean square errors of the best-performing models were 17–38%. The models using texture data performed better than the model using only data on soil bulk density and organic carbon.

Keywords: soil thermal diffusivity, mathematical modelling, pedotransfer functions
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INTRODUCTION

The thermal diffusivity of soil is equal to the ratio between soil thermal conductivity and volumetric heat capacity and reflects the ability of soil to conduct heat and change temperature due to heat input or loss. The higher is the soil thermal diffusivity, the thicker is the active layer where temperature fluctuations are observed and the smaller are temperature fluctuations on the soil surface. Thermal diffusivity is generally not a constant value typical for some or other soil, but it can significantly vary in time, which is primarily related to the natural dynamics of soil water content [25, 26, 29]. The range of this variability and the form of dependence between thermal diffusivity and water content are primarily determined by the texture and bulk density of soil and the content of organic carbon [7, 14].

The estimation of soil thermal properties and their dynamics is necessary for the simulation of joint heat and moisture transfer in soils [27] and the balance of energy fluxes at the soil–atmosphere interface [23], as well as for the solution of different engineering problems [15, 24].

Most of the existing models for the thermal diffusivity and thermal conductivity of soils were trained on relatively small experimental data sets, frequently of regional character, and give large errors when applied to soils with different ranges of texture, bulk density, and humus content [1, 16, 17, 23, 30–32].

The aim of this work was to develop a mathematical model for calculating the thermal diffusivity of soils with different textures and different water contents from data on their bulk density, particle size distribution, and organic carbon content.

OBJECTS AND METHODS

Thermal diffusivity vs. water content dependencies obtained for sandy, loamy, and clayey soils of European Russia were used for the development and calibration of models. The training set included Brunic Arenosols and Anthrosols (Arenic) (Chashnikovo Research and Experimental Station), Albic Retisols (Arenic) (Prioksko-Terasny Nature Biosphere Reserve), Albic Luvisol (Siltic) (Zaokskie Pitomniki farm, Tula oblast), Calcic Chernozem (Siltic) (Kamennaya Steppe National Park, Voronezh oblast), and Epigleyic Chernic Phaeozem (Siltic) (Ignat'evskii village, Republic of Adygeya).

The thermal diffusivity of undisturbed samples was determined by the unsteady-state method under laboratory conditions [2, 14, 21]. A series of measurements was performed for each sample, and a dependence between thermal diffusivity and water content was obtained in the range from capillary saturation to the air-dry state. After the measurements of thermal diffusivity, bulk density, organic carbon content, particle density, and particle size distribution were determined